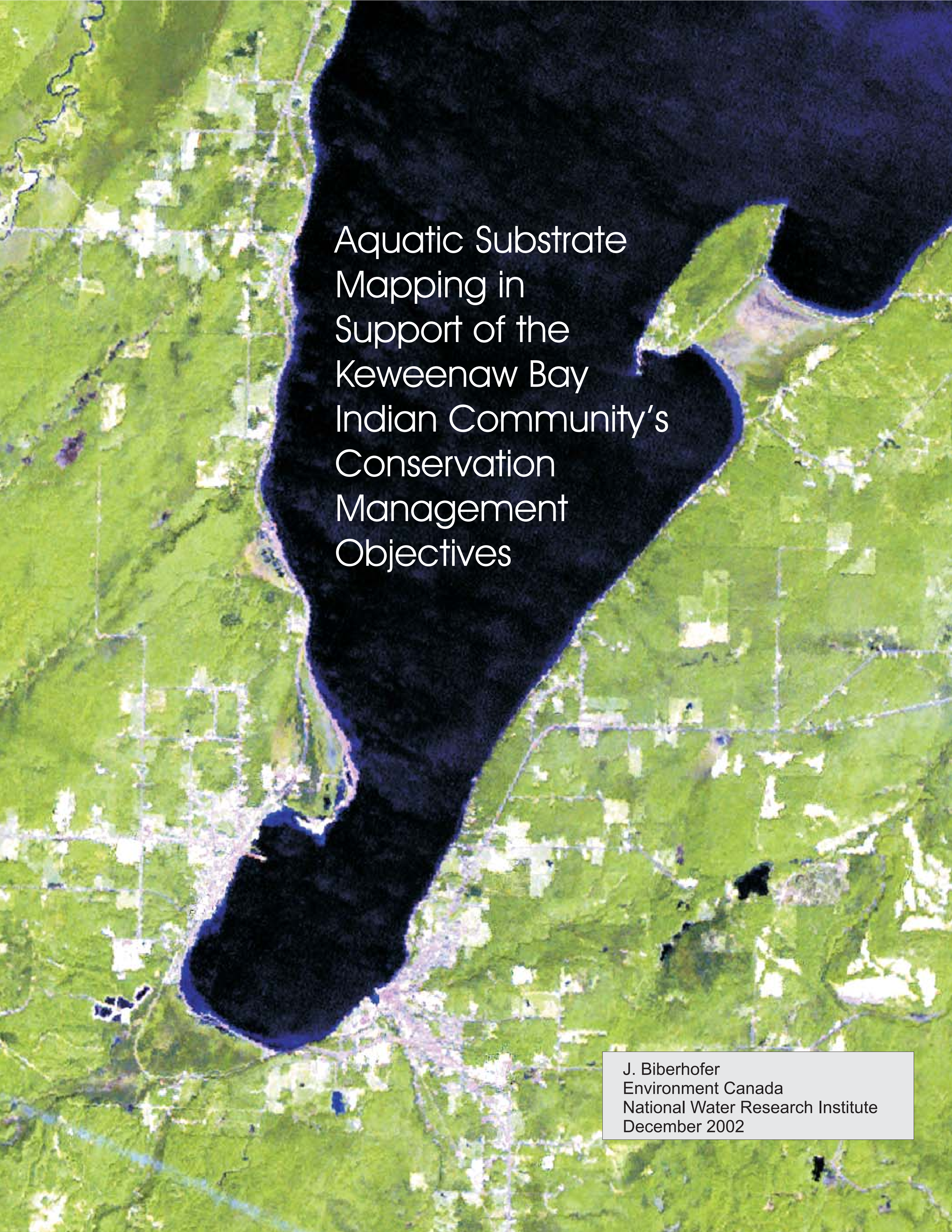

Aquatic Substrate Mapping in Support of the Keweenaw Bay Indian Community's Conservation Management Objectives

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Introduction:

The determination of the quality and quantity of aquatic habitat is essential component of conservation management. The types of habitat required for particular fish species changes through the life history of the fish. The opportunity for the fish to exploit successive habitats is often a function of the connectivity or habitat corridors available to the fish. Furthermore, the quality of these habitats can be often impacted by land-based activities or extraction of resources, which have become either integrated with or are co-located with particular habitats.

A key objective of conservation management is to protect critical habitats and their corridors from degradation, disturbance or exploitation. Delineation of these habitats is an important element in the management and conservation of these resources.

The Keweenaw Bay Indian Community (KBIC) management responsibilities for the natural resources in the southern portion of Keweenaw Bay. Members of the Natural Resources staff are active in both regional conservation management initiatives as well as participating in broader Lake Superior basin programs. KBIC aquatic programs include an established fisheries monitoring program in Keweenaw Bay and operation a fish hatchery using native brood stock.

The National Water Research Institute (NWRI) of Environment Canada has successfully used an acoustic seabed classification system to map the distribution of aquatic substrates for a range of program objectives including the distribution of contaminated sediment deposits, sediment geometry and fisheries habitat. There is an on-going research effort into refining procedures and developing technologies to improve the robustness of the measurements.

This report summarizes the methods employed by NWRI staff and the results achieved from an acoustic mapping survey of aquatic substrate. This study was the result of scientific partnership initiated by the KBIC Natural Resources Department in support of their conservation management objectives.

Study Area:

The study area is located in the waters of the southern portion of Keweenaw Bay, Lake Superior in the Upper Peninsula of Michigan (Figure 1). Adjacent to the Bay are the lands of the Keweenaw Bay Indian Community, and the municipalities of Baraga, MI and L' Anse MI, which are located on the southwest and southeast shores of Keweenaw Bay respectively. Forested land and cottages border most of the remaining shoreline. The study area extended to the northern boundary of the Keweenaw Bay Indian Community reservation.

The Bay is characterized as a deep trench with narrow littoral shores on the east and west shores. The southern end of the bay, L'Anse Bay, has water depths of 30 m or less and is bordered by a sand beach and wetlands on the southern end. Shallower waters extending approximately 1.5 km from shore also characterize Pequaming Bay at the northeast reach of the study area. It is also has a sand beach and wetlands as the predominant shoreline features. For the purposes of this study, the Bay was divided into 4 operational units L'Anse Bay, Pequaming Bay, east shore and west shore (Figure 2).

The study effort concentrated on areas with water depths ranging from 2 m to 20 m along the narrow littoral shelves and in the 2 bays. This water depth range was selected to be inclusive of all depths for which lake trout spawning has been observed in the Great Lakes (Marsden et al, 1995). Of particular interest are shoals that are adjacent to the steep slopes rising from the deep water of the bay. When the fish come up to the shoals from the deeper depths, the littoral areas that have suitable habitat and are immediately adjacent to the steep slopes are often the primary spawning sites. (J. Fitzsimons, personal comm.)

Survey Schedule

The study took place from June 04, 2002 to June 12, 2002. The first half-day was dedicated to launching the boat and system setup. Data collection started in the afternoon of June 04, 2002. Acoustic mapping continued each day for 7 to 9 hours per day and concluded at noon on June 09, 2002. Favorable weather conditions and long periods of daylight made it possible to complete the equivalent of 6 days of soundings (460 km) during 5 days on the water.

Underwater video work started in Pequaming Bay the afternoon of June 09, 2002. Video survey work continued June 10, 2002 in L'Anse Bay and the west shore and continued in June 11, 2002 at sites along the east shore. Sediment sampling started on June 11, 2002 in Pequaming Bay and concluded unexpectedly on June 12, 2002 near Baraga when a cable became caught in the winch, damaging the drive mechanism.

Field Procedures

Positioning

A Differential Global Positioning System (DGPS) was used to collect position data for the soundings, underwater video and sediment sampling. The standard procedure to determine accuracy and precision of the DGPS is to place the GPS antenna from the boat directly on top of an established geodetic benchmark. Position data is recorded and the accuracy and precision of the system is determined for the beginning and end of each survey

A geodetic benchmark was not available to assess accuracy for this survey. Precision was determined by tying the boat up at the exact same location each day along the dock and recording a series of position records. This data was used to provide a measure of the day-to-day variability. The quality of the DGPS signal as determined by the number of satellites being used and differential signal from the beacon were routinely monitored on the DGPS readout. The system typically has a sub-meter accuracy when stationary and 2 to 3 meter accuracy when the boat is moving. The beacon used for the corrections was the Upper Keweenaw, MI beacon located 47° 13.62344'; 88° 37.45902'.

Substrate Mapping - RoxAnn

Acoustic mapping of surface sediment with a RoxAnn™ seabed-classification system (Rukavina 1998, Rukavina and Cadell 1997) has been used at a number of sites in the Great Lakes basin to investigate the distribution of substrate types.

The RoxAnn surveys were conducted between June 04, 2002 and June 09, 2002. The survey vessel Puffin, a 9-m aluminium launch, was equipped with a dual-frequency (50kHz and 200 kHz) digital Knudsen sounder (Model 320M) with in-hull transducers. The return signal from the sounder was processed with a RoxAnn seabed-classification system.

Positions were determined with a DGPS with corrections from the Keweenaw Bay beacon. The RoxAnn-output signal, G1 (roughness) and G2 (hardness), was converted to acoustic labels by Microplot™ survey software running on a notebook computer. Microplot logged the labels and the corresponding DGPS positions at 1-second intervals and displayed them in real time on a geo-referenced map (Figure 3). Survey lines were initially run at 100 m offsets. The density of mapping was increased to 50 m offsets in nearshore areas with water depths less than 20 m. (Figure 4).

RoxAnn response to a simulated sounder signal was logged at the beginning and end of each survey day to confirm equipment integrity and stability.

Underwater video

An underwater camera mounted on a weighted tripod was used to collect underwater video records of the substrate. The legs of the tripod have 10 cm color gradations useful for comparing substrate size and depth of penetration when the camera is lowered onto the substrate. A GPS antenna was mounted on the davit used for lowering the camera. At fixed target sites efforts were made to keep the boat stationary or at very low speeds to optimize the vertical and position accuracy between the antenna and the camera lowered in the water. A video mixer combined the position information from the DGPS and the video from the camera (Figure 5). At some sites, particularly those sites that transitioned from sand to cobble or at sites where the substrate was heterogeneous due to debris; it was useful to record video transects as the boat drifted or move slowly under power. During some instances, the position information was degraded up 3 meters due to slope of the line from the davit to the camera's tripod.

The video was recorded in a digital format on 8mm tape. Selected segments of the video were then recorded as computer images and computer video files for portability as well as to be included in a Geographic Information System (GIS) project.

Sediment sampling

Sediment samples were collected with a Shipek sampler that is very effective at collecting surface sediment. This layer of sediment has the most effect on the characteristics of the high-frequency return echo recorded with the RoxAnn seabed classification system (Figure 6). The sampler was deployed from a winch and davit setup on the launch with a GPS antenna mounted on the davit, similar to the setup for the underwater video. The collected sediment was described, photographed and sub-sampled for particle size analyses (Duncan and LaHaie, 1979).

Data Analysis

Sediment Mapping - RoxAnn

RoxAnn data were edited using spreadsheet macros to remove records for which the actual water depths were less than 2 m or when the boat speeds were less than 2 m/s and greater than 5 m/s when the soundings were recorded. Two meters is the shallow-water limit of the high-frequency RoxAnn system. Boat speeds outside the 2 to 5 m/s range result in shifts of RoxAnn labels to coarser and harder sediment classes than are actually present (N. Rukavina, personal comm.). Water depth data were adjusted to International Great Lakes Datum (IGLD) 1985 based on records from the water-level gauging station located at Marquette, MI (Station 9099018 Marquette C.G., MI, Northing 5154673.15 Easting 470993.74 Zone 16N) using a six-minute interval and time referenced to Eastern Standard Time.

The edited data resulted in a dataset of 141,764 soundings. A plot G1 (roughness) vs. G2 (hardness) showed a small subset (66 records) of the edited data that had much larger than expected G1 values. To avoid having this subset bias the analyses, these records were excluded from the dataset. The final number of records used was 114,698.

The dataset was imported into Systat ® (Version 10, SPSS Inc.) a Windows based statistical software package. To expedite testing for the most appropriate classification scheme, a subset of 20% (22,987 records) of the original dataset were randomly selected using an algorithm included in Systat. The test records were then clustered using the Systat Kmeans procedure with Euclidean as the distance metric and number of iterations set to 20. Several combinations were tested using G1, G2 and depth as the variables and the number of clusters was varied using 6, 7, 8 and 12.

To compare the influence of water depth on the cluster assignment, identical runs were executed with and without depth as variable for both the 6 and 8 cluster assignments. Only 35 of the 22987 cases (0.15%) had different cluster assignments when depth was included as a variable in the 6-cluster test. There were 69 cases (0.30%) that were different for the 8-cluster test. As there was little difference between the methods, cluster assignments were determined using G1 and G2 as the variables (Figure 7).

The dataset and the cluster identifier file were merged and exported into an ArcView © (Environmental Systems Research Institute Inc (ESRI)) readable format. The cluster identifier was then mapped as a substrate class in an ArcView GIS project. The substrate label was determined by comparing substrate class with the images of the substrate, which were extracted from the underwater video records. Using the ArcView "Hot-link" feature, it was possible to make direct visual comparisons of the substrate label and the substrate image (Figure 8). Video segments were also linked to the project using a similar method.

Selected video images were also matched with the nearest RoxAnn soundings that were not greater than 4m away using a custom in-house SAS procedure. Once selected, the G1 and G2 from the nearest sounding were plotted and points were labelled using the description from the underwater video images. There was a good correspondence between range of the RoxAnn signal and the substrate type observed.

The grain size analysis from the thirteen sediment samples (Appendix 1) was also compared with the substrate labels and the images.

Results and Discussion

After comparing all the data, the best description of the substrate types was with 6 clusters or classes. These classes represent 5 substrate groups: mud/muddy sand, compact sand/fine-grained material on hard substrate (FOH), sand, cobble and wood debris. The sixth class was designated as transition; it was prevalent along the borders of cobble fields where there was mix of cobble and sand. This substrate class was also used to describe zones where substrates were a complex of other substrates often found in areas exposed to wave energy (Figure 9).

L'Anse Bay

This Bay is the largest shelf within the study area with maximum depths ranging from 20 m to 30 m with mud and muddy-sands as the predominant substrate type (Figure 10). North and immediately adjacent to the Village of Baraga Marina there is a large amount of wood debris from historical lumbering and sawmill industries. This debris is in sufficient quantity to cluster into a distinct substrate class. Wood debris and scattered logs continue to be present south of the marina to the mud/muddy sand substrate boundary. It is most likely that the debris field extends further out into the deeper water than the substrate map indicates. Most of the debris is sawmill slabs that would have minimal profile; this combined with an overlying layer of silt would mask the substrate to the acoustic signal.

The shallower water of the southeast portion of the Bay results in a shift in substrate types from sands then fine-grain material overlying a hard substrate (FOH), which borders distinct zone of transition type substrate. Underwater video shows this Bay is generally a zone of fine-grained material overlying hard substrate with occasional wood debris ranging from small wood fragments to tree stumps (Figure 11). Patches of cobble were also mapped in this area, but may be artifact of the debris on the hard substrate. No video information was collected to confirm the cobble substrate type. The distribution of this zone is consistent with the expected water discharge pattern from the Falls River.

East Shore

The east shore zone is a narrow sill 7.5 km long and 300 m to 500 m wide, and connects L'Anse Bay and Pequaming Bay. The shoreline has low-lying bluffs and long continuous areas of exposed rock and cobble. It is exposed to predominant northwest winds and most likely subject to ice scour (Figure 12).

The substrate is a series of bands parallel to the shoreline and is a combination of several classes of substrate, transition, sand and compact sand/FOH classes. Figure 13 is an example of FOH substrate encountered in this area. This banding is consistent a gradation of substrate changes controlled by slope, wave action, and currents. Fine-grained particles are washed from the immediate nearshore and settle on hard substrate in the lower energy depths. These particles, when moved by wave action, can oscillate in and out in the nearshore but closer to the steep edge they are lost to the deeper water. Ice scour would further limit any substantial accumulation of fine-grained material.

Some of the transect lines alternated between transition and compact sand/FOH classes. The roughness and hardness measures were compared at points of change and most of the change to transition was due to hardness rather than roughness although some debris was noted in this zone (Figure 14). Almost all the transition class substrate at depth was coincident with the edge of the steep slope to deeper water and consistent with a loss of sediment to the deeper waters. The substrate mapped as transition in the nearshore was a mix of sand and cobble.

Small patches of cobble were found in 4 areas of the east shore zone. Each of these patches was immediately adjacent to valleys in the bluffs (perennial streams) bordering the bay with one valley composed of Little Silver Creek.

Pequaming Bay

Similar to L'Anse Bay, Pequaming Bay has a substantial littoral shelf with water depths less than 30m and is approximately 1 to 1.5 km wide. The inshore border of the shelf has a wide band of shallow water and compact sand waves as the predominant substrate. There is a distinct change in bottom substrate to mud/muddy sand, which follows a contour between the inshore border and the deeper waters of the shelf. This pattern, as seen in the other areas studied, is consistent with sorting of the particles by wave energy and focusing the finer particles into deeper waters (Figure 15).

The northeast corner of Pequaming Bay is littered with wood debris consisting of logs and sawmill slabs (Figure 16). The co-occurrence of silt and almost neutrally buoyant wood chips, which persist in this part of the Bay as it is protected from prevailing winds, act to soften the acoustic return echo resulting in the substrate being classed as transition rather than debris. Near the entrance to the private marina in Pequaming Bay, portions of the substrate are correctly labeled as debris. There is also a mix cobble, transition to compact sand substrates, which coincides with more energy reaching the bottom due to the shallower water depths. NOAA charts indicate cribs, but our sampling avoided these areas.

The southeast corner of the bay, which is more exposed to waves, has patches of cobble and transition substrate. These patches are a continuation of the zone of similar substrate identified at the north end of the east shore zone (Figure 17).

West Shore

While the beach is relatively narrow where the Little Carp River enters the bay, the littoral shelf (water depth less than 20 m) extends approximately 1.4 km offshore. South towards Sand Pont Light the width of the beach increases and the littoral shelf tapers in-shore; 600 m north of the Sand Point Light the beach and the littoral shelf rapidly narrow and end (Figure 18). This was only location in the study area where there was noticeable water currents during the time of the survey. The absence of a littoral shelf around Sand Point may represent a significant break in the continuity of littoral habitat between the west shore and L'Anse Bay.

The west shore substrate distribution is comparable to the east shore and the exposed reaches of Pequaming Bay (Figure 18). The shallow waters have well-defined compact sand waves with little or no visible silt on the surface. As the water depths increase, the sand waves are still evident but because there is less wave energy at depth the sand is not as compact. This transition to a less dense surface substrate is consistent with the mapped changes in substrate classification within the littoral shelf of the west shore.

The most striking contrast, and perhaps the most critical for fish spawning, is the two zones of cobble substrate at the north end of the west shore zone. Sandstone bluffs border this area and the southern and smaller of the 2 cobble fields is immediately offshore of the Little Carp River (Figure 19). Transition substrate, a mix of sand and cobble, was found at the edges of both cobble areas (Figure 20).

Heads-up digitizing of the boundaries was used to calculate rough estimates of the area for each of the cobble fields as being 5.6 ha and 40 ha for south and north areas respectively. It needs to be noted that the northern boundary of the north cobble field was not determined (since it was north of the study area) and as such could be considerably larger than the 40 ha polygon.

Sections of the west shore are exposed to a northeast open water fetch of approximately 230 km. Northeast storms could have a dramatic impact on the beaches and shallow water substrates. The success of these cobble fields as spawning substrate may be determine by the effects of northeast storms.

High-energy storm events could potentially remobilize and transport along the shoreline large amounts of sand and finer particles. A portion of this flux is known to contain stamp sands, a waste product, from historical mining operations, that was disposed of along the shoreline north of the study area (M. Donofrio, personal comm.). It was not possible with the acoustic technology employed in this study to differentiate the stamp sands from the native sands.

Areas of Extreme Roughness (G1) measurements

As noted in the description of the data procedures, there was a subset of data (66 points), which had very high G1 values with no corresponding increase in hardness measurements. While these data points were not included in any of the analyses, as they represented less than 0.06% of the dataset, the points were mapped to determine if there was spatial significance to their distribution. A cluster of 44 of the 66 points was located at the southern end of the west shore study area. Coincidently, the underwater video recorded single large submerged upright poles immediately to the north and south of this cluster of points (Figure 21). While the purpose for poles is unknown and any connection to the high roughness measurements is speculative, it is interesting that both artifacts are co-located.

Summary

The aquatic substrates of the Keweenaw Bay study area are dominated by sands. These sands are sorted to varying degrees by the energy they are exposed to as a function of water depth and wave action (fetch). The accumulation of fine-grained mud and muddy-sands in L'Anse Bay and Pequaming Bay is consistent with the observed water current patterns, fetch and the bathymetric features of the bays.

At the mouth of each tributary to the Keweenaw Bay study area there was a shift in the character of the substrate. This was most evident where the Little Carp River discharges to the west shore (compact sand to cobble) and for the Falls River flow that enters at L'Anse Bay (sand to FOH to transition). It was also evident for the smaller tributaries (Little Silver Creek and other perennial streams) along the east shore where small patches of cobble were found. Additional sampling should be conducted north of the west shore zone to further define the associated cobble field.

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Marsden, J.E., Casselman, J.M., Edsall, T.A., Elliot, R.F., Fitzsimons, J.D., Horns, W.H., Manny, B.A., McAughey, S.C., Sly, P.G., and Swanson, B.L. 1995. Lake Trout Habitat – A Review of Current Knowledge. J. Great Lakes Res. 21(Supplemental):487-497

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Rukavina, N.A. and Caddell, S.E. 1997. Applications of an acoustic sed-bed classification system to freshwater environmental research and remediation in Canada. *In* Proceeding, 4th Conference on Remote Sensing for Marine and Coastal Environments, Orlando, Fls., March 1997.

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Brian Trapp, NWRI, AEMRB provided field support and technical expertise during the survey. He was also responsible for post-processing the video data.

Marilyn Dunnett, contractor to the program, edited and processed the RoxAnn data.

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Figures

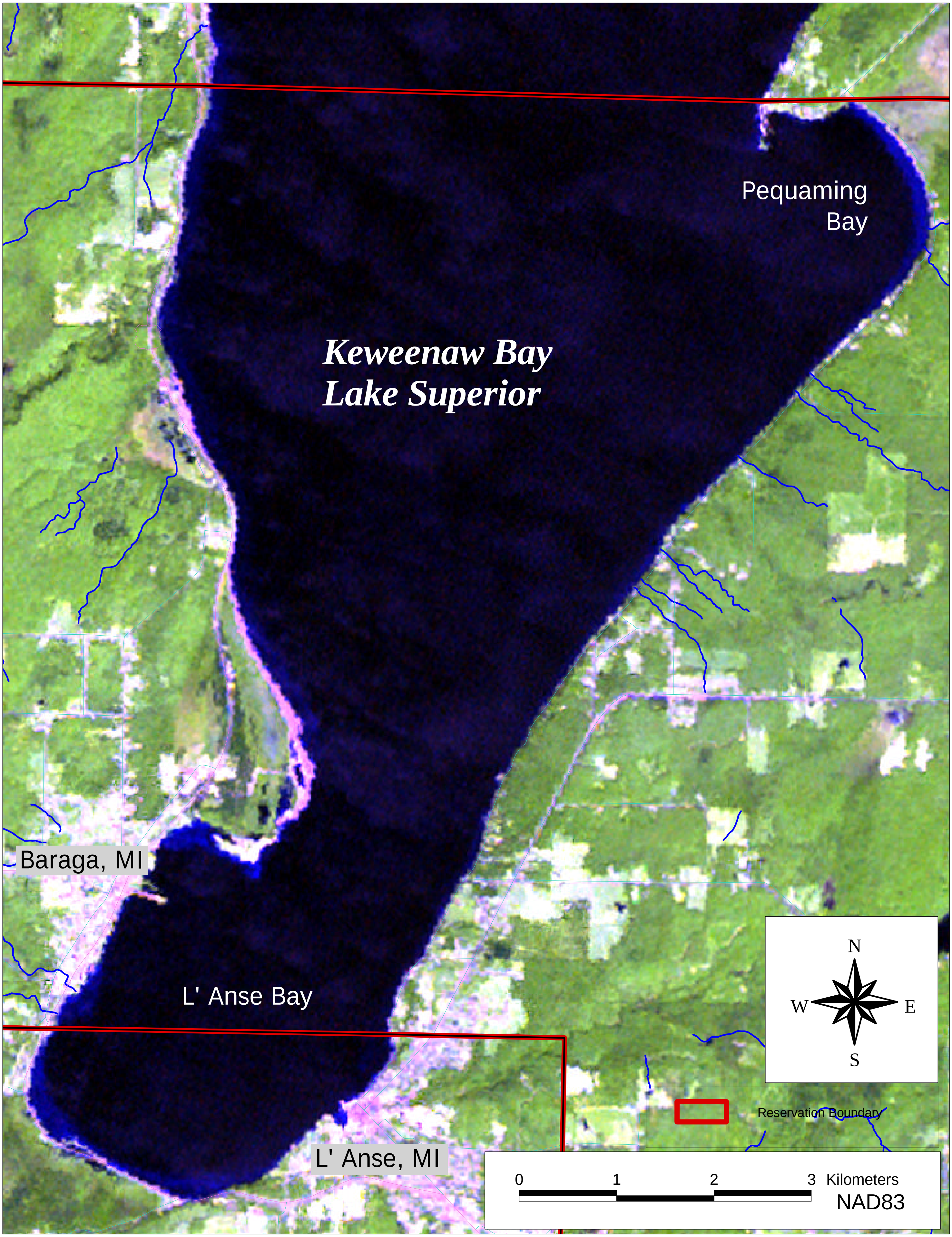


Figure 1: Study Area

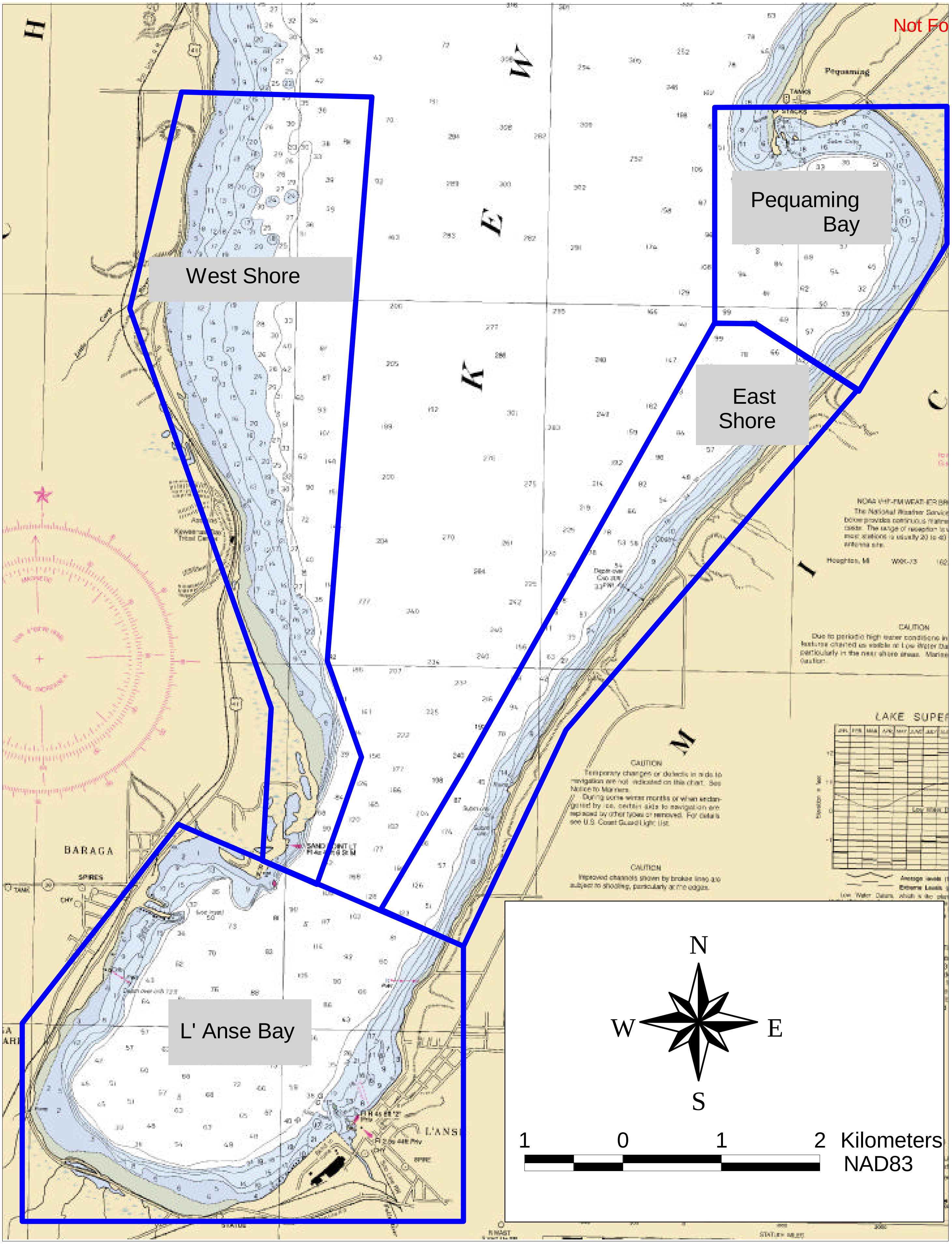


Figure 2: Study Zones

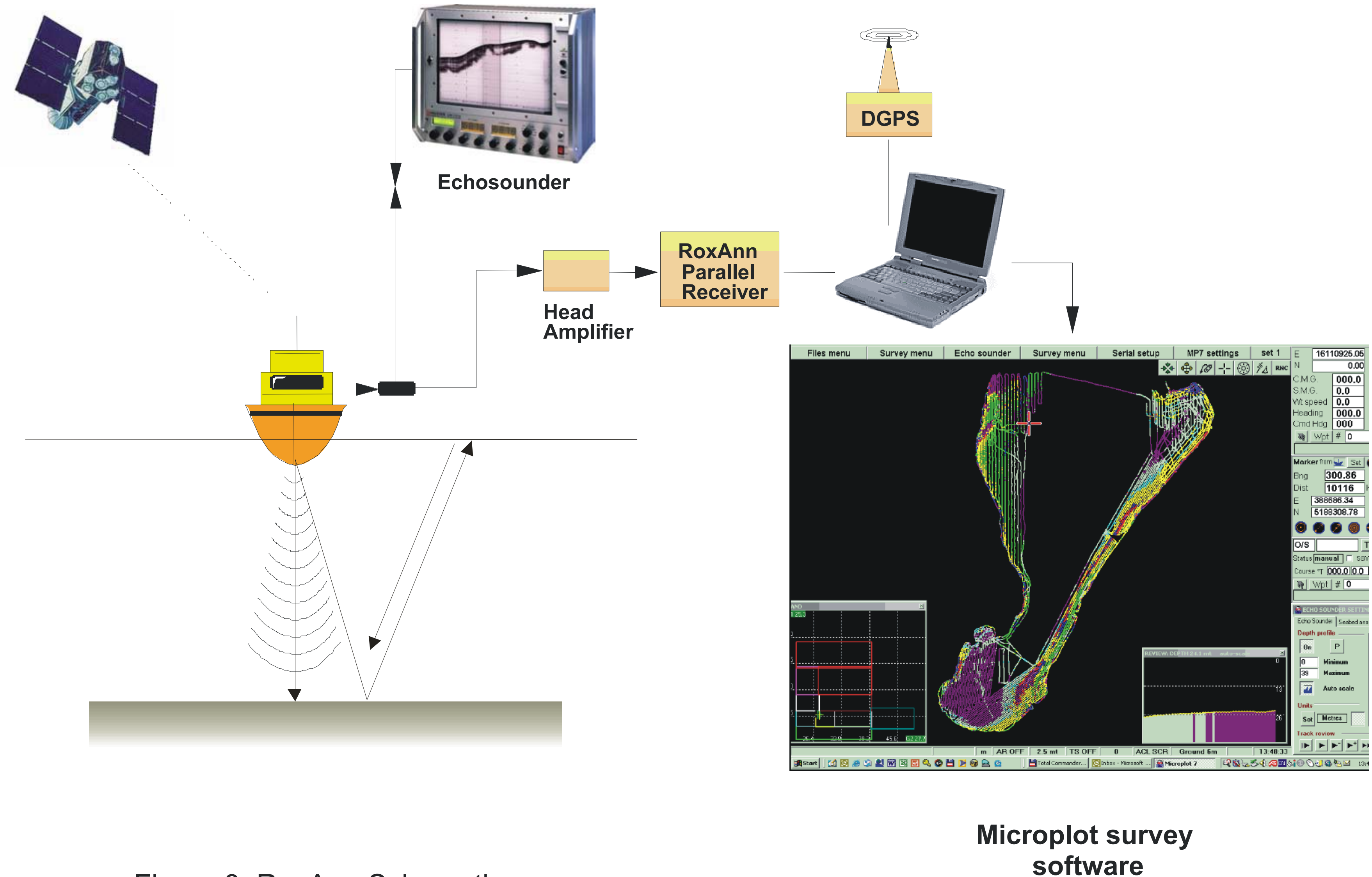


Figure 3: RoxAnn Schematic

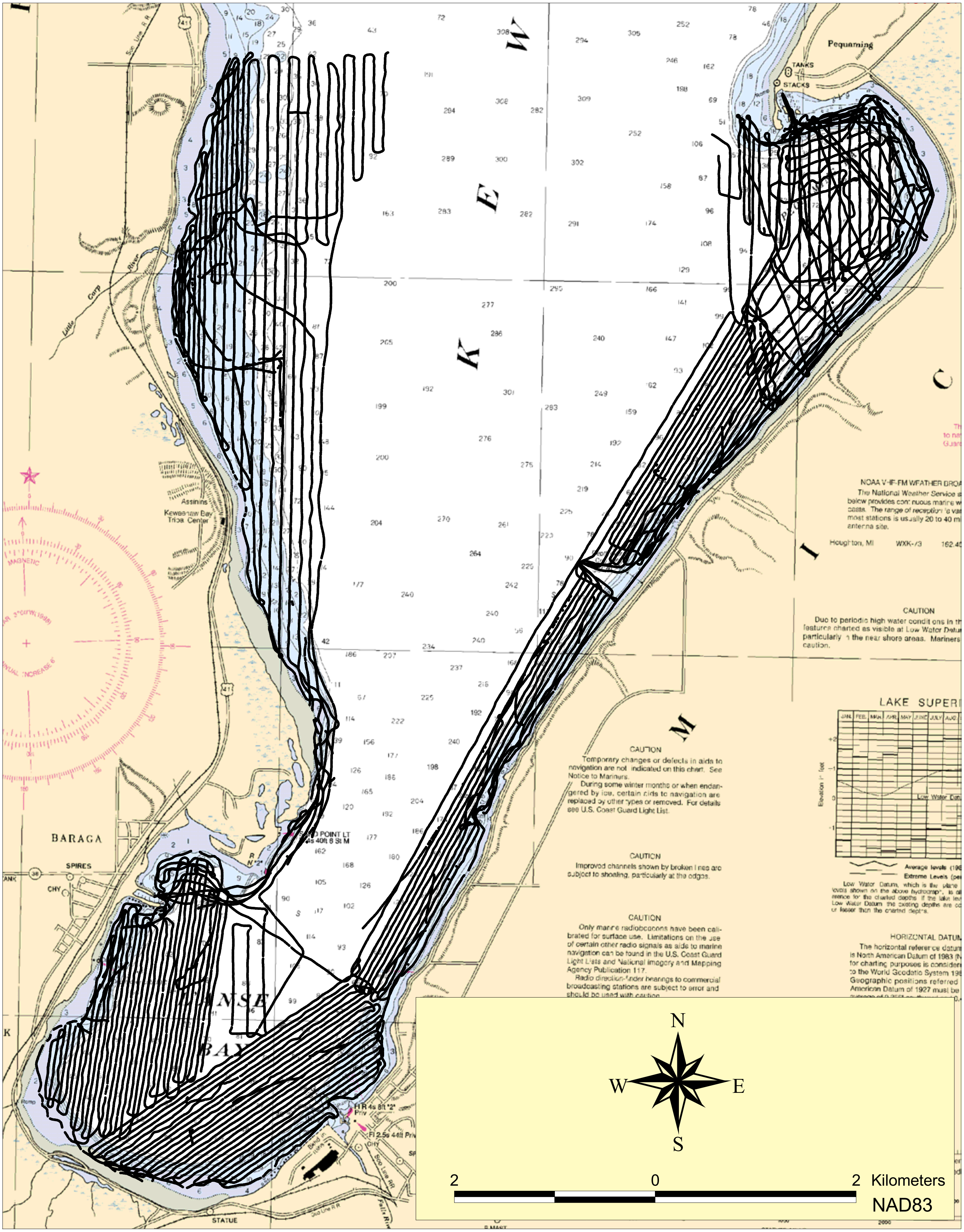


Figure 4: RoxAnn survey track lines

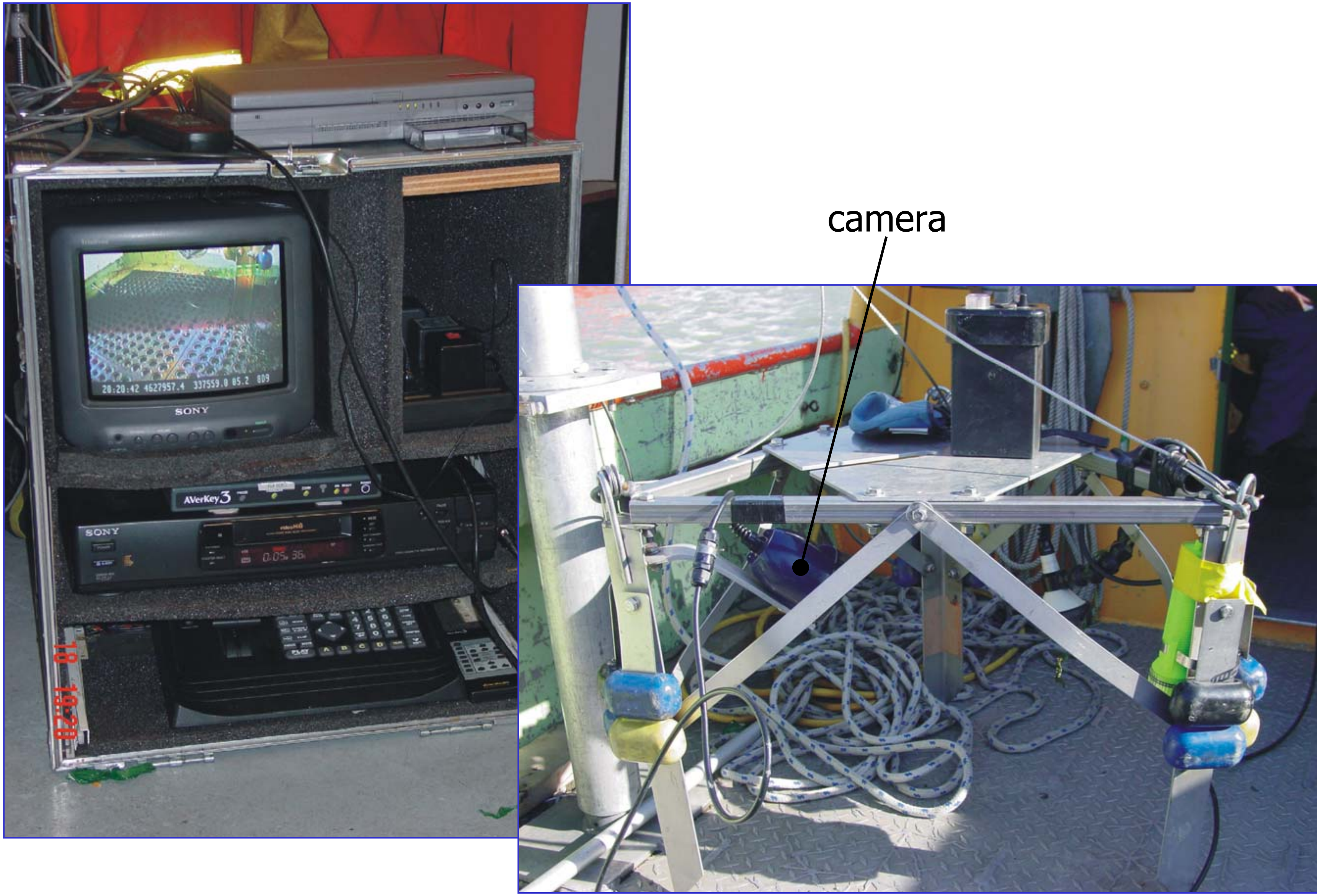


Figure 5: Underwater video set-up

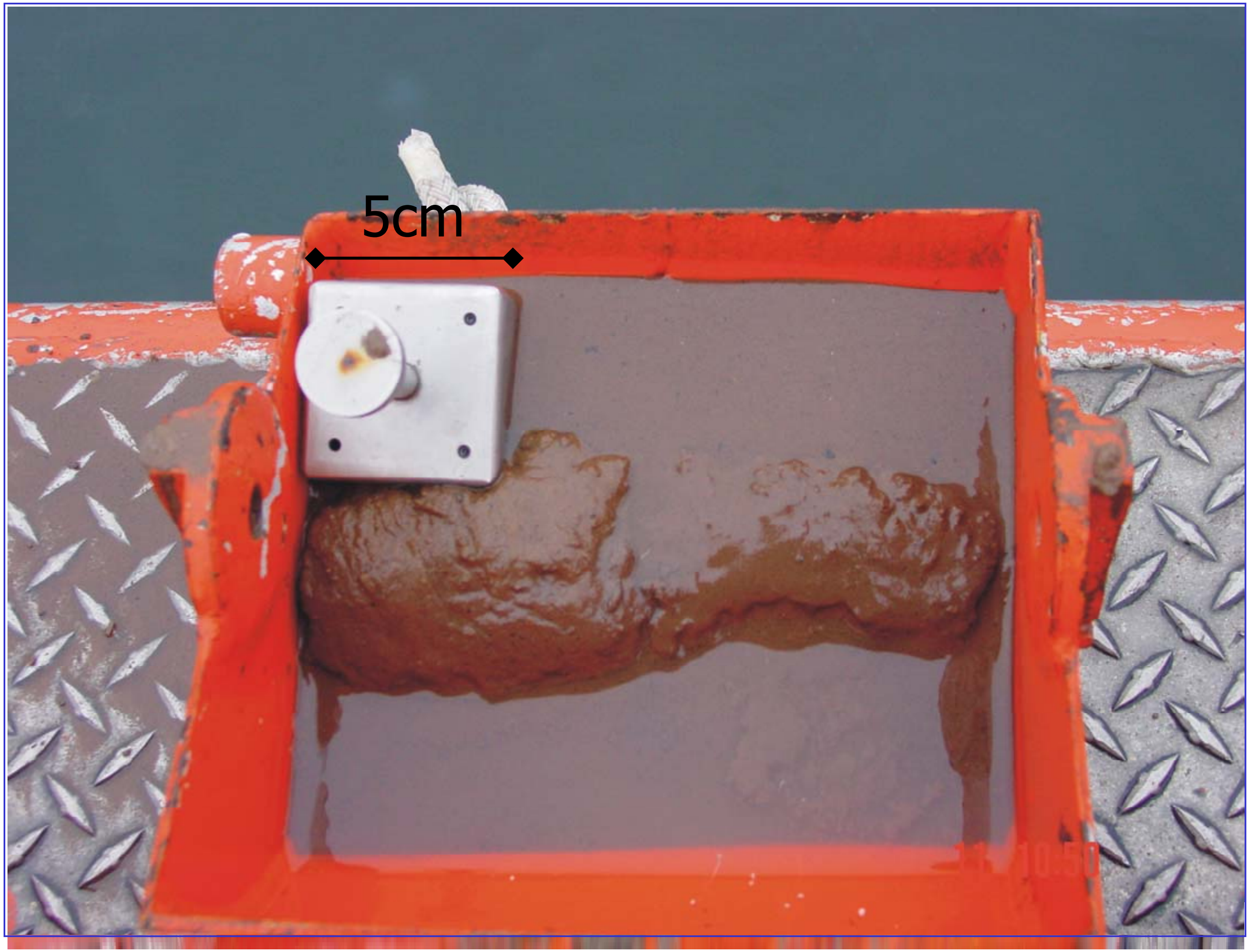


Figure 6:Shipek sediment sample

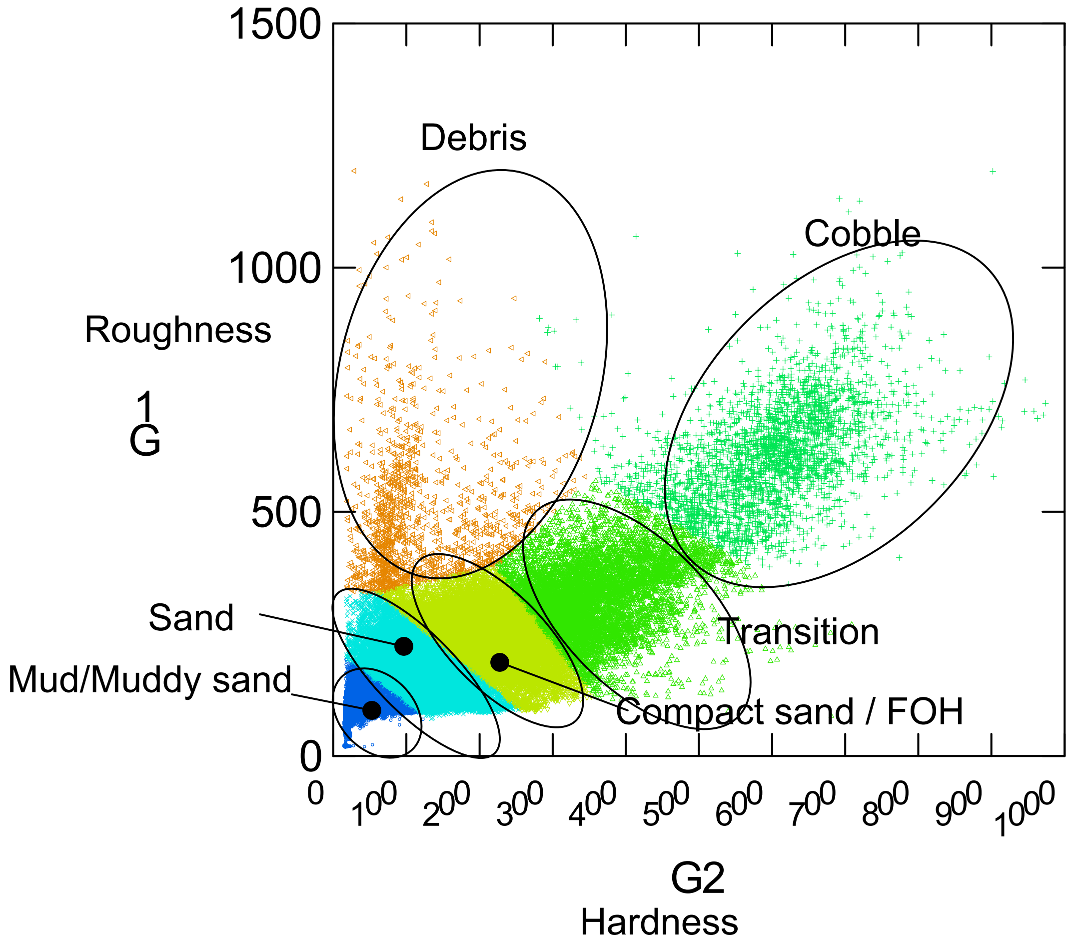


Figure 7: Scatter plot of G1 and G2 measurements (6 clusters)

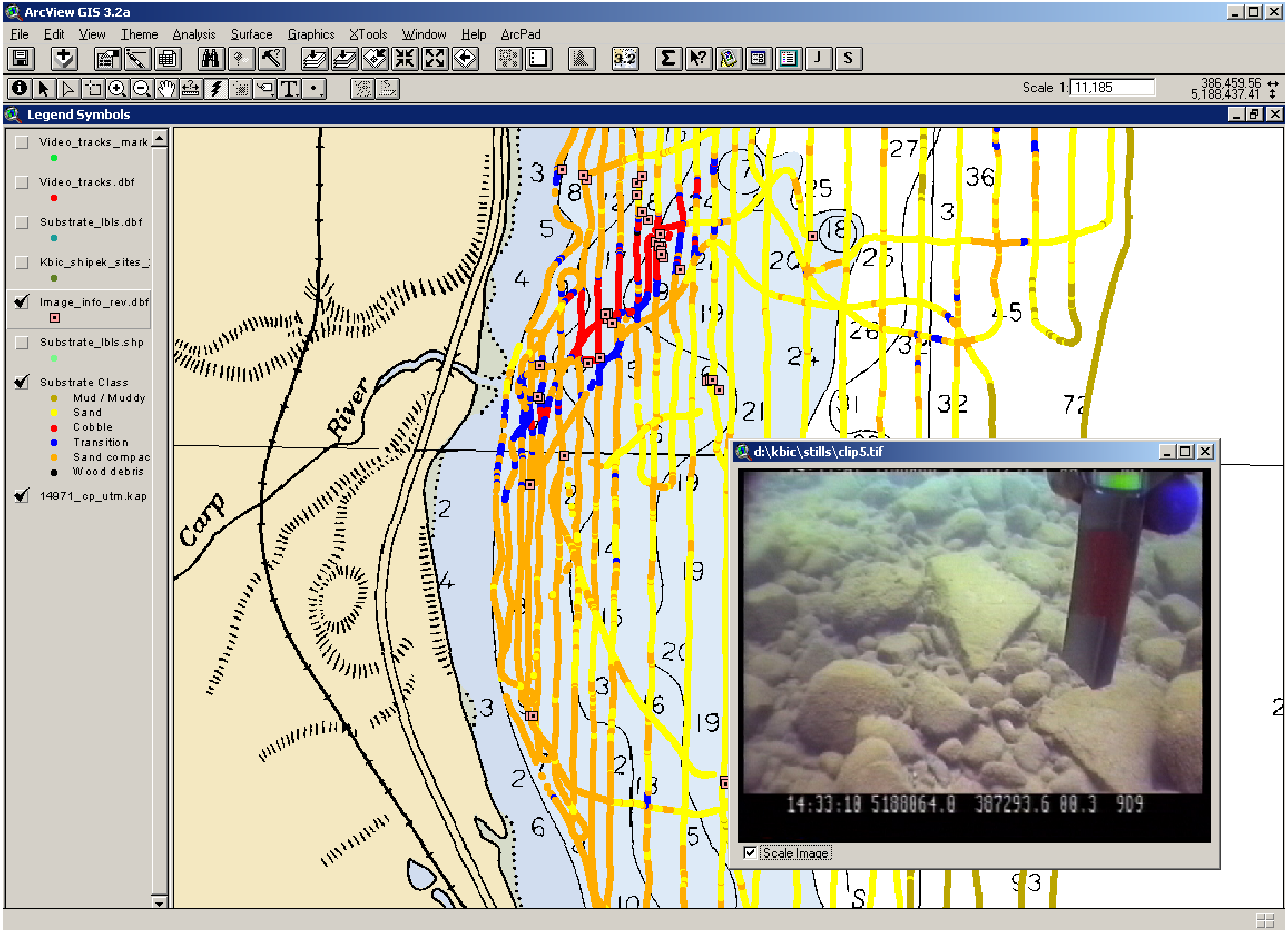
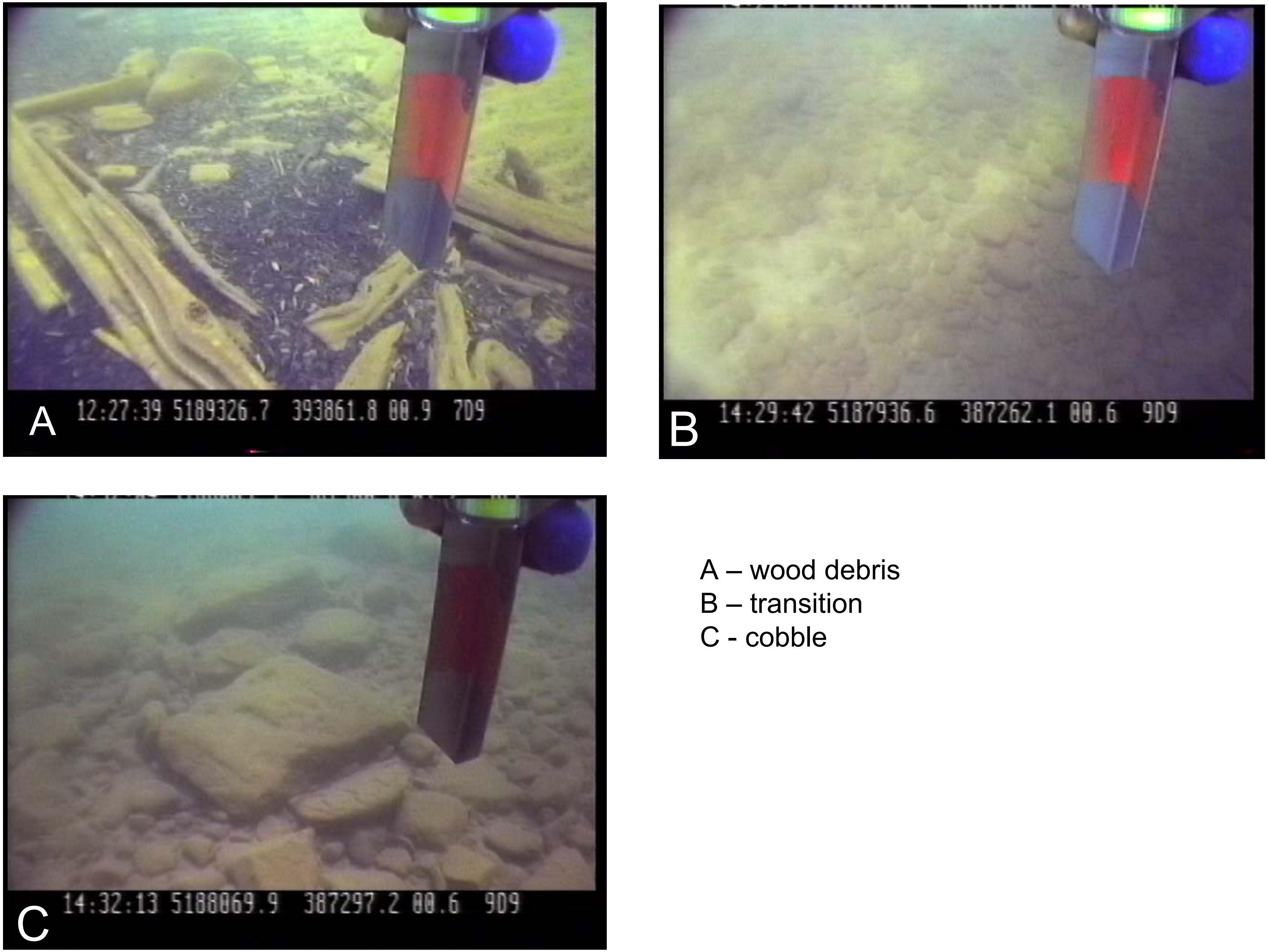
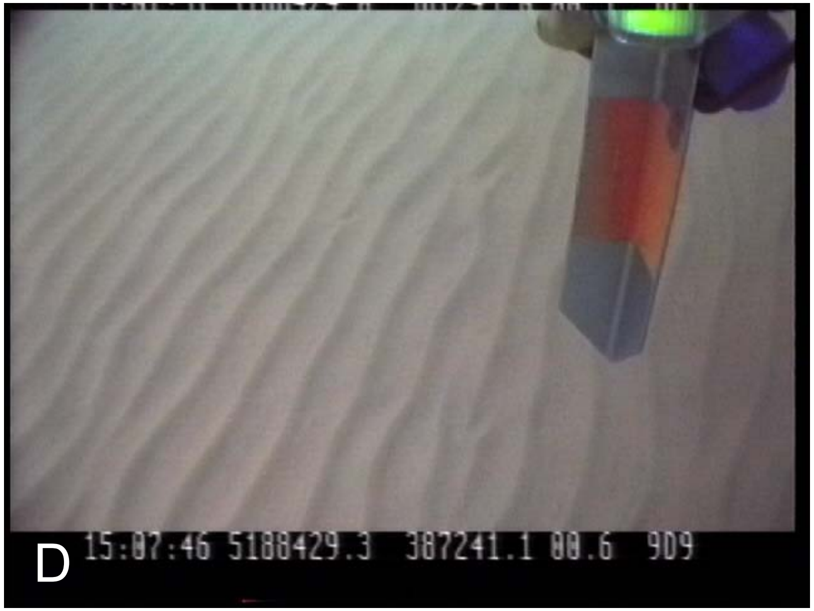


Figure 8: Example of using “hot-link” images to evaluate substrate classification



A – wood debris
B – transition
C - cobble

Figure 9: Examples of substrate classes



D – compact sand
E – sand
F – mud / muddy sand

Note tripod has
sunk to maximum

Figure 9: Examples of substrate classes (continued)

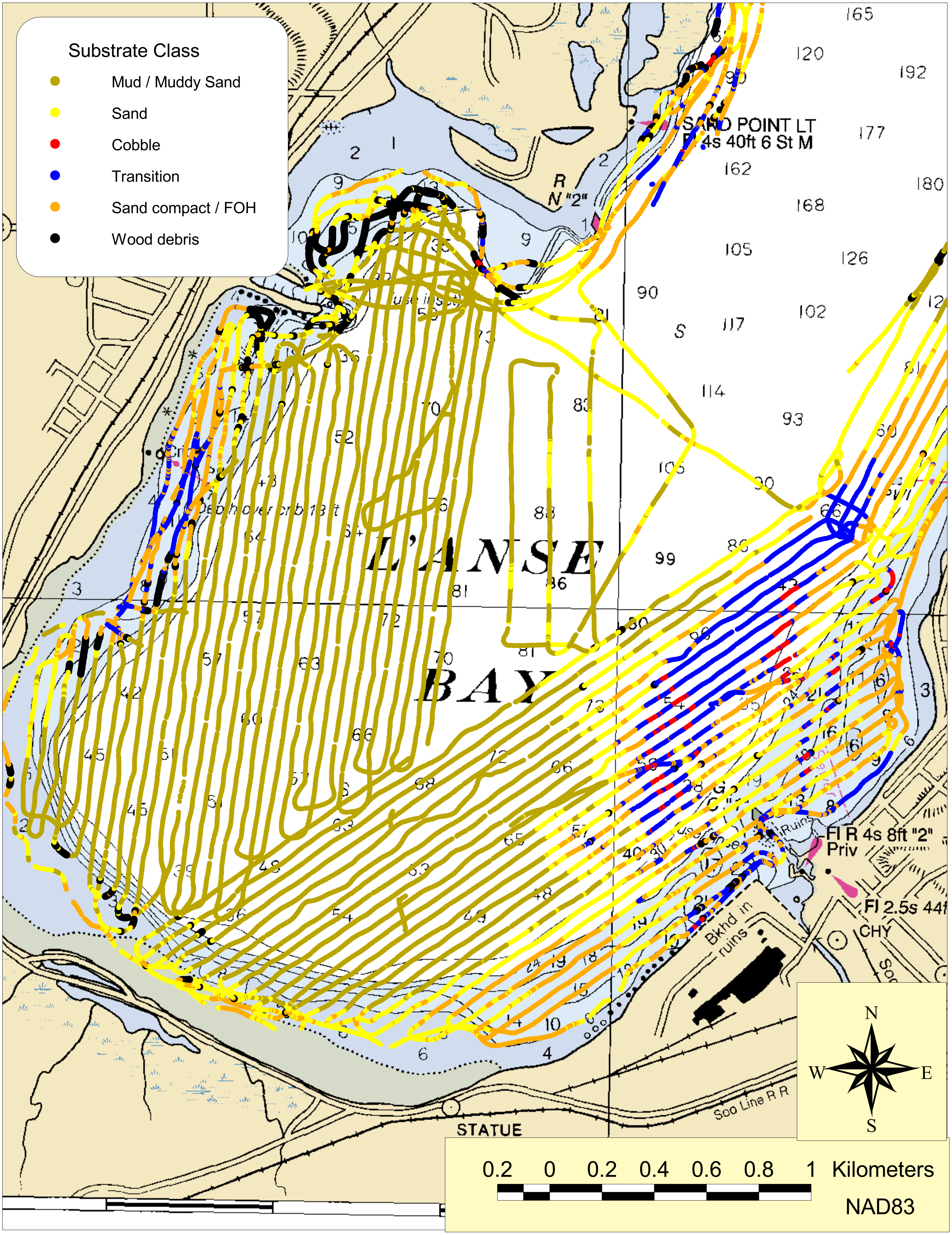


Figure 10: L' Anse Bay substrate map.

Figure 11: L’ Anse Bay – debris offshore of Falls River

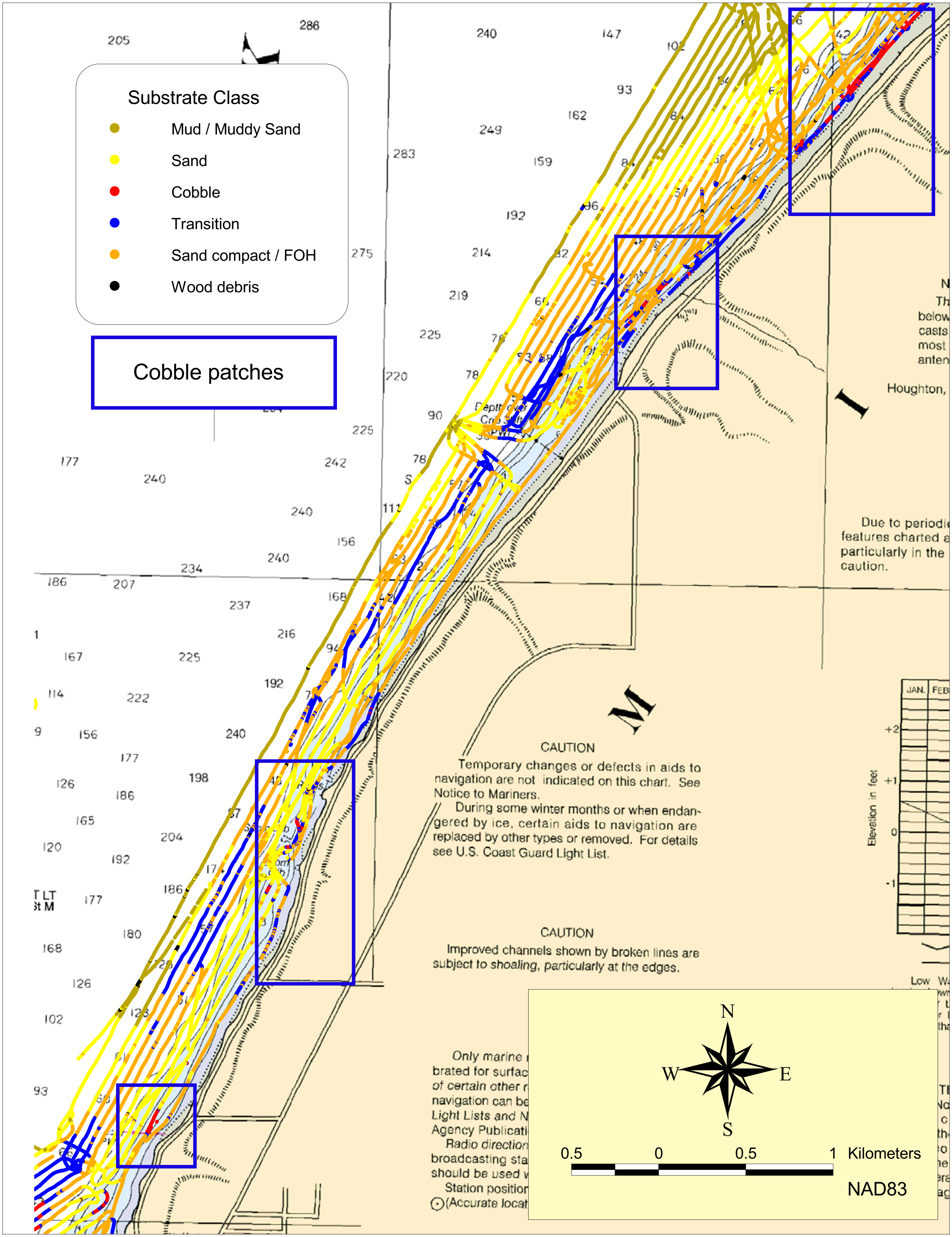
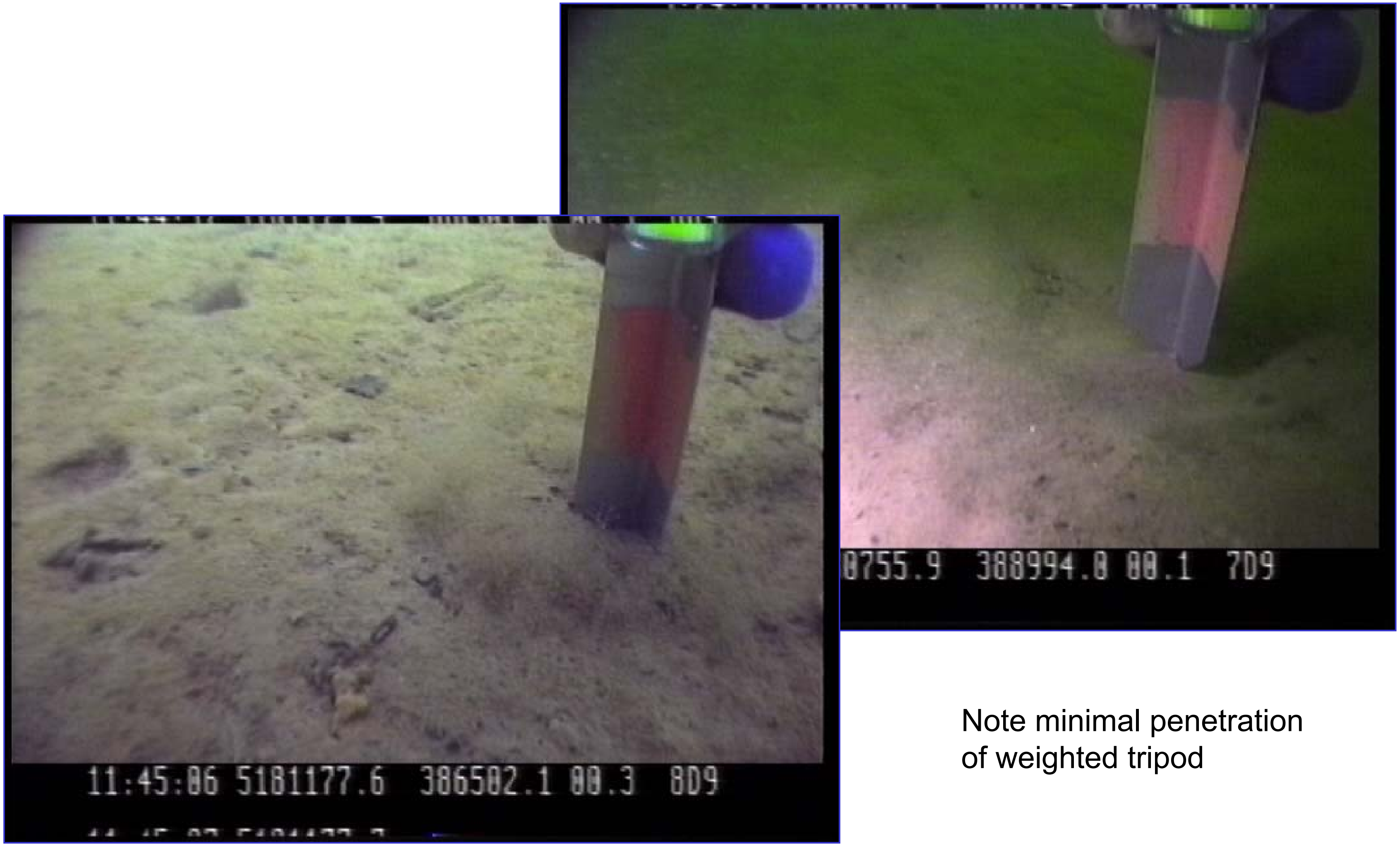


Figure 12: East Shore substrate map.



Note minimal penetration
of weighted tripod

Figure 13: Example of Fine-grain sediment on hard substrate (FOH)

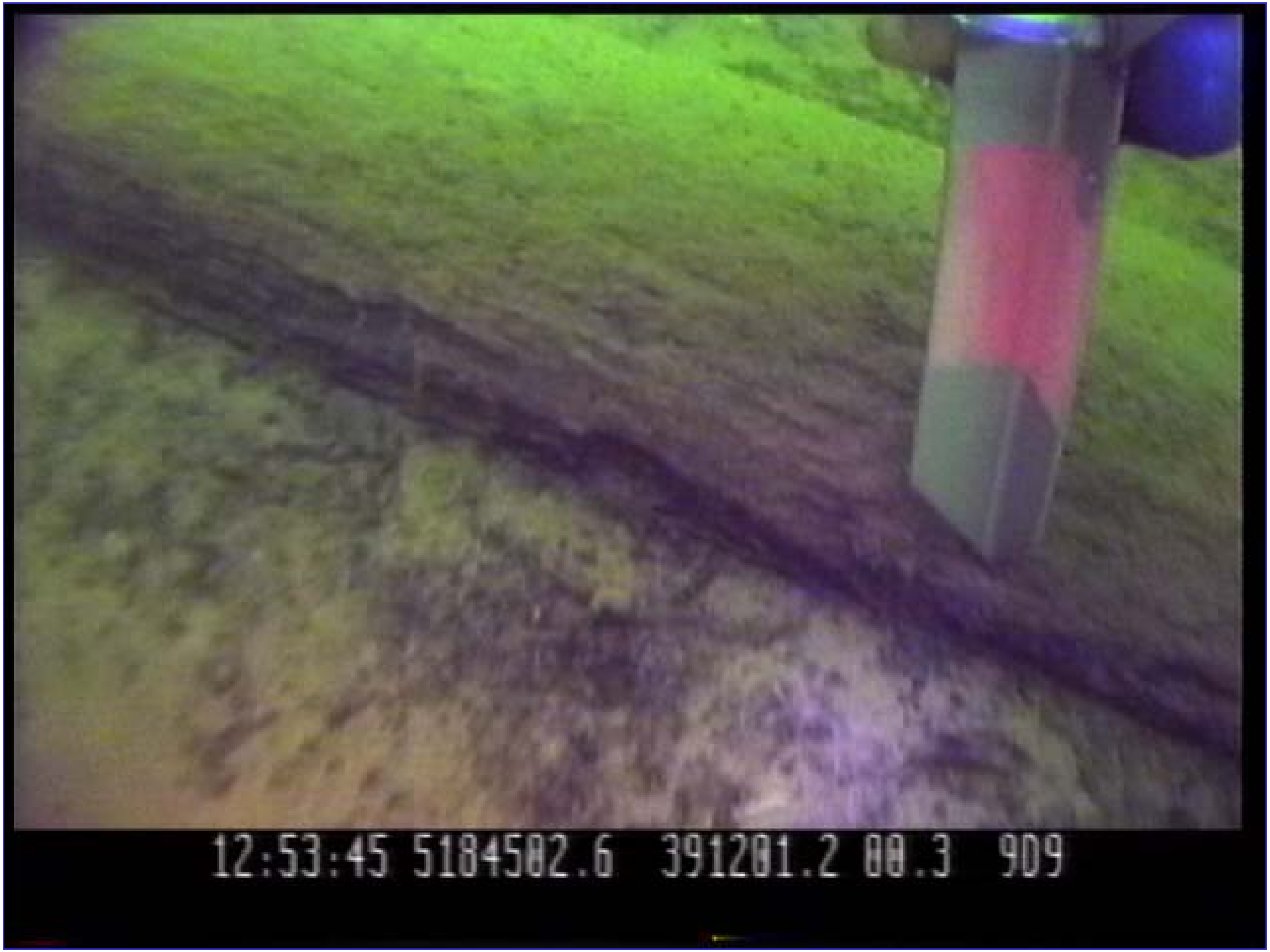


Figure 14: East Shore wood debris

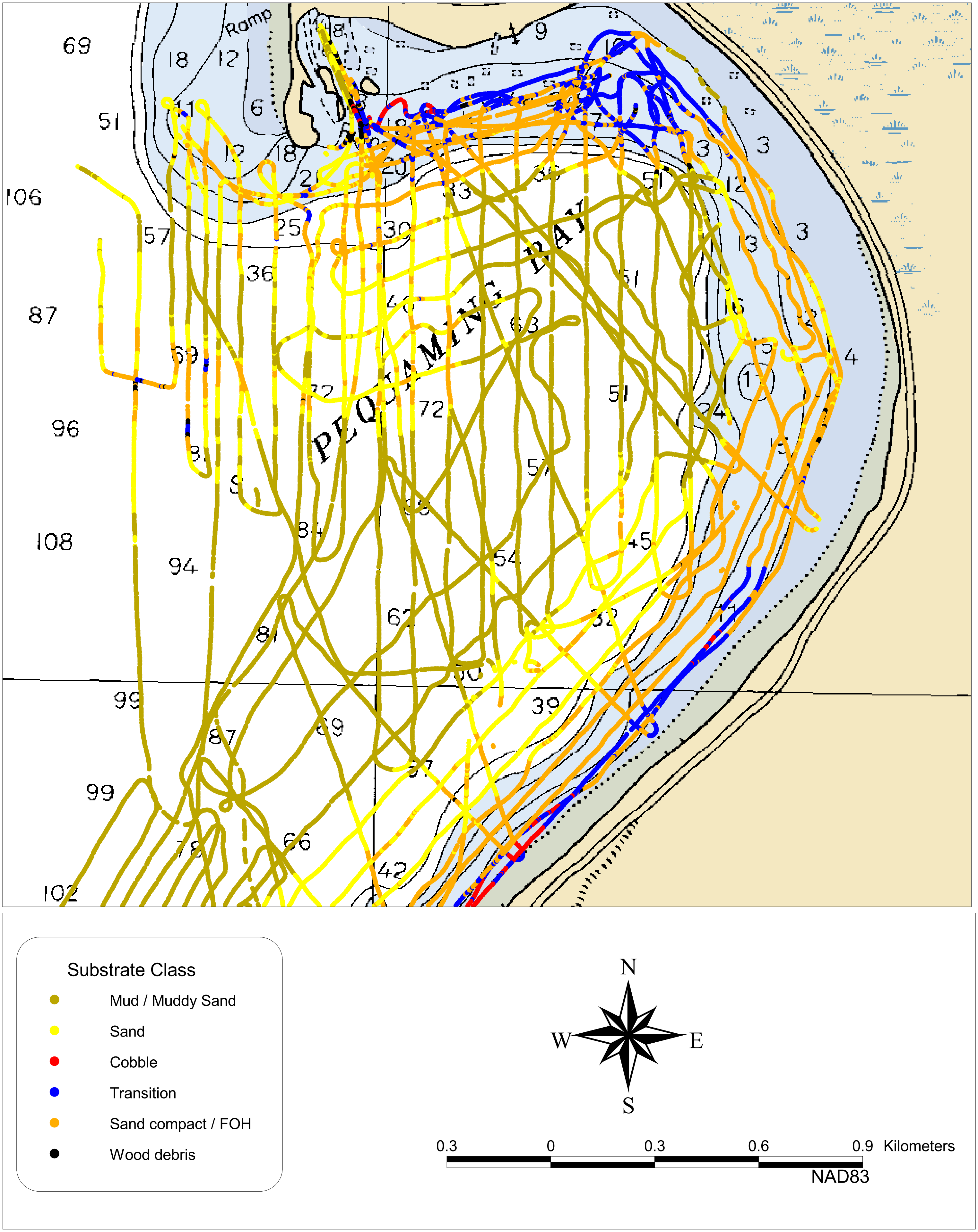


Figure 15: Pequaming Bay substrate map.

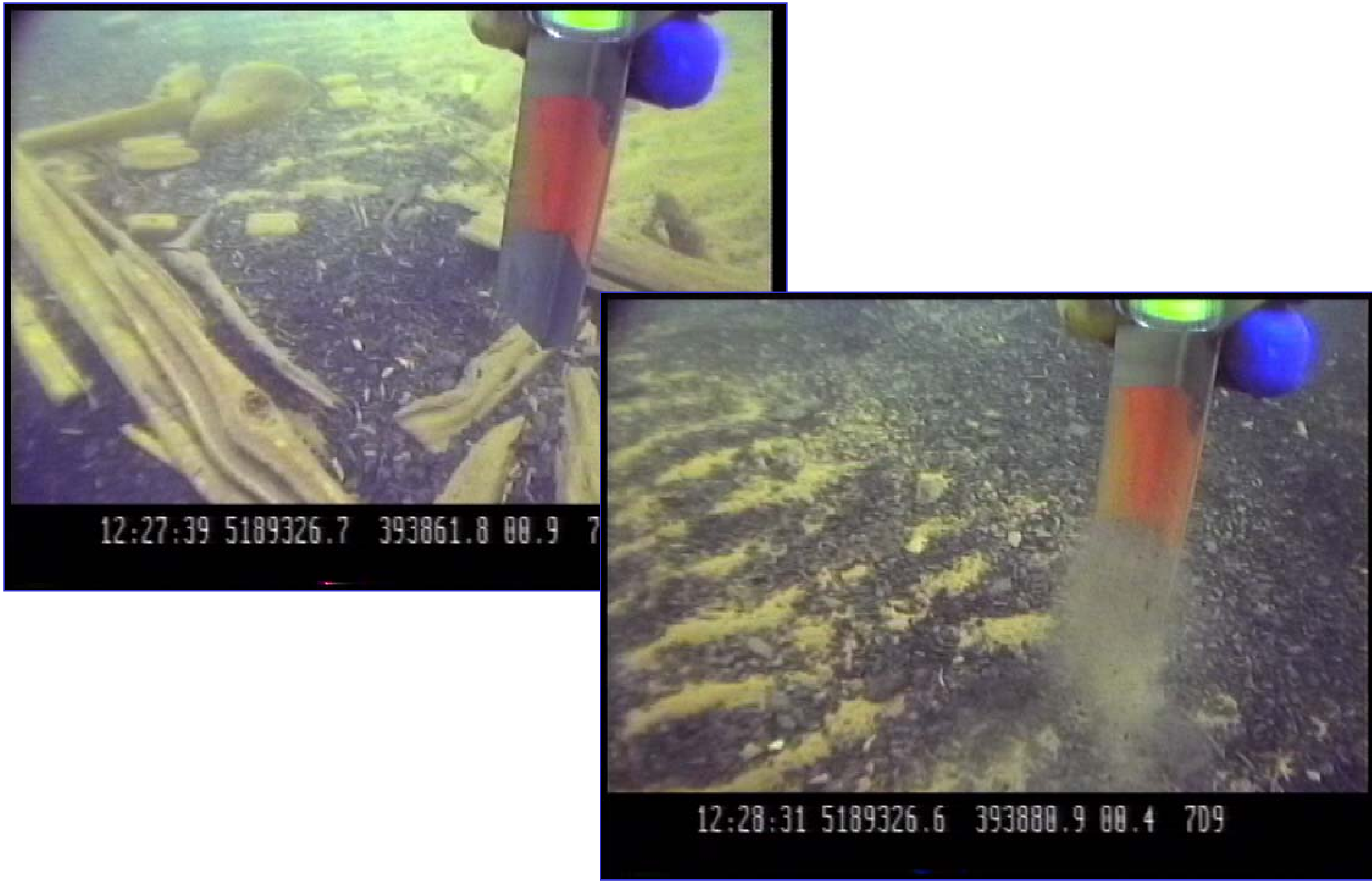


Figure 16: Pequaming Bay - wood litter and debris

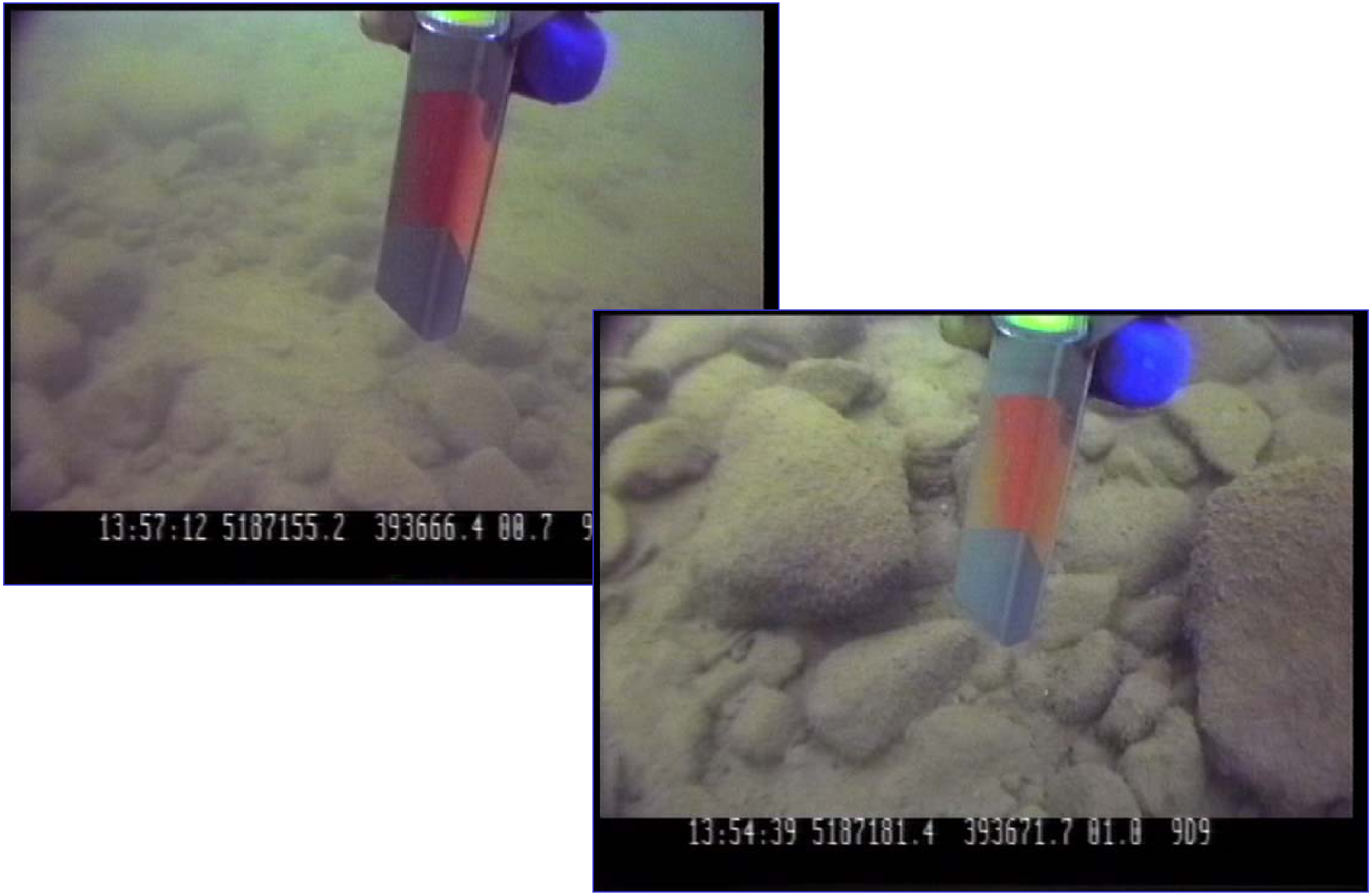


Figure 17: Pequaming Bay: Cobble in southeast corner.

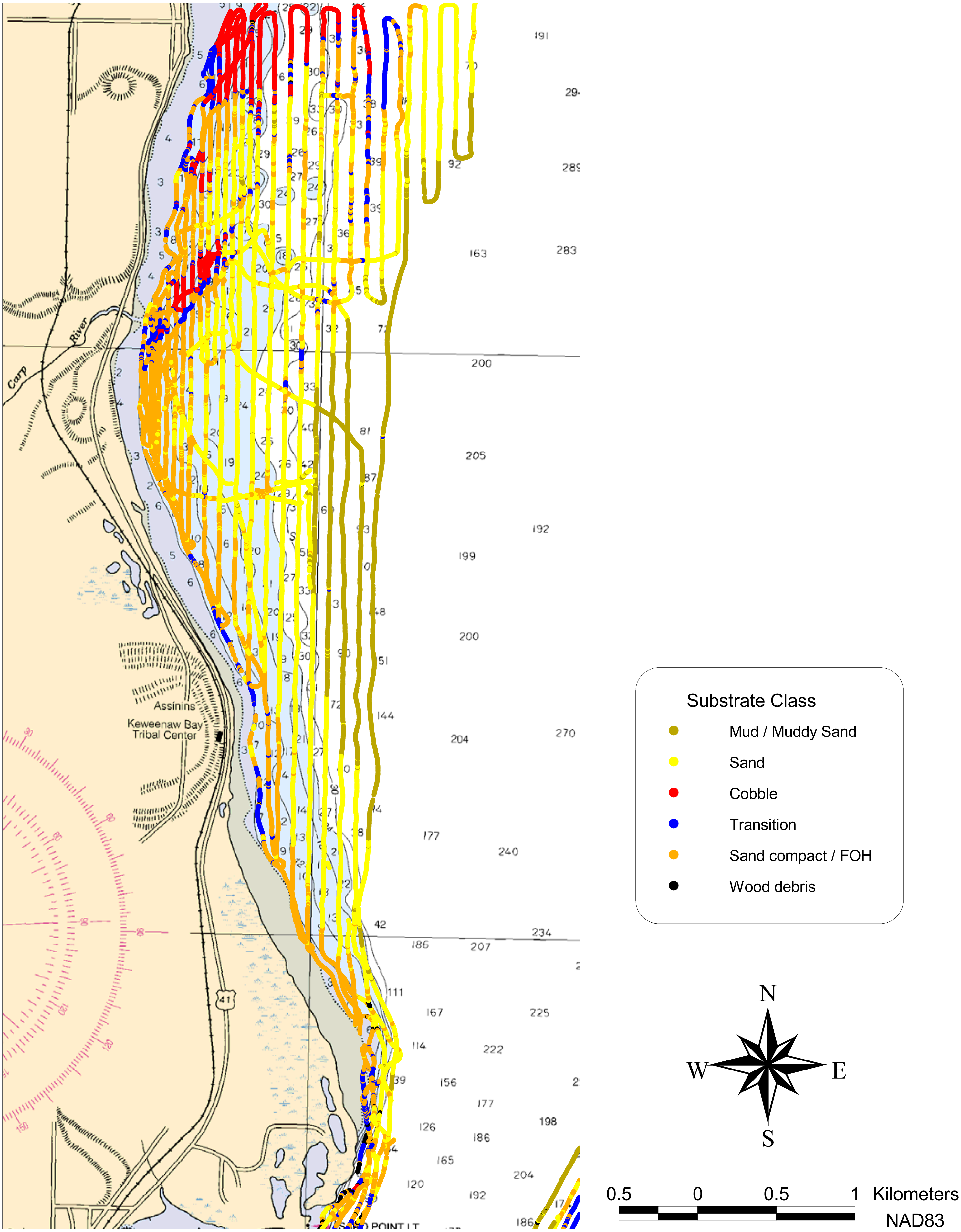


Figure 18: West Shore substrate map.

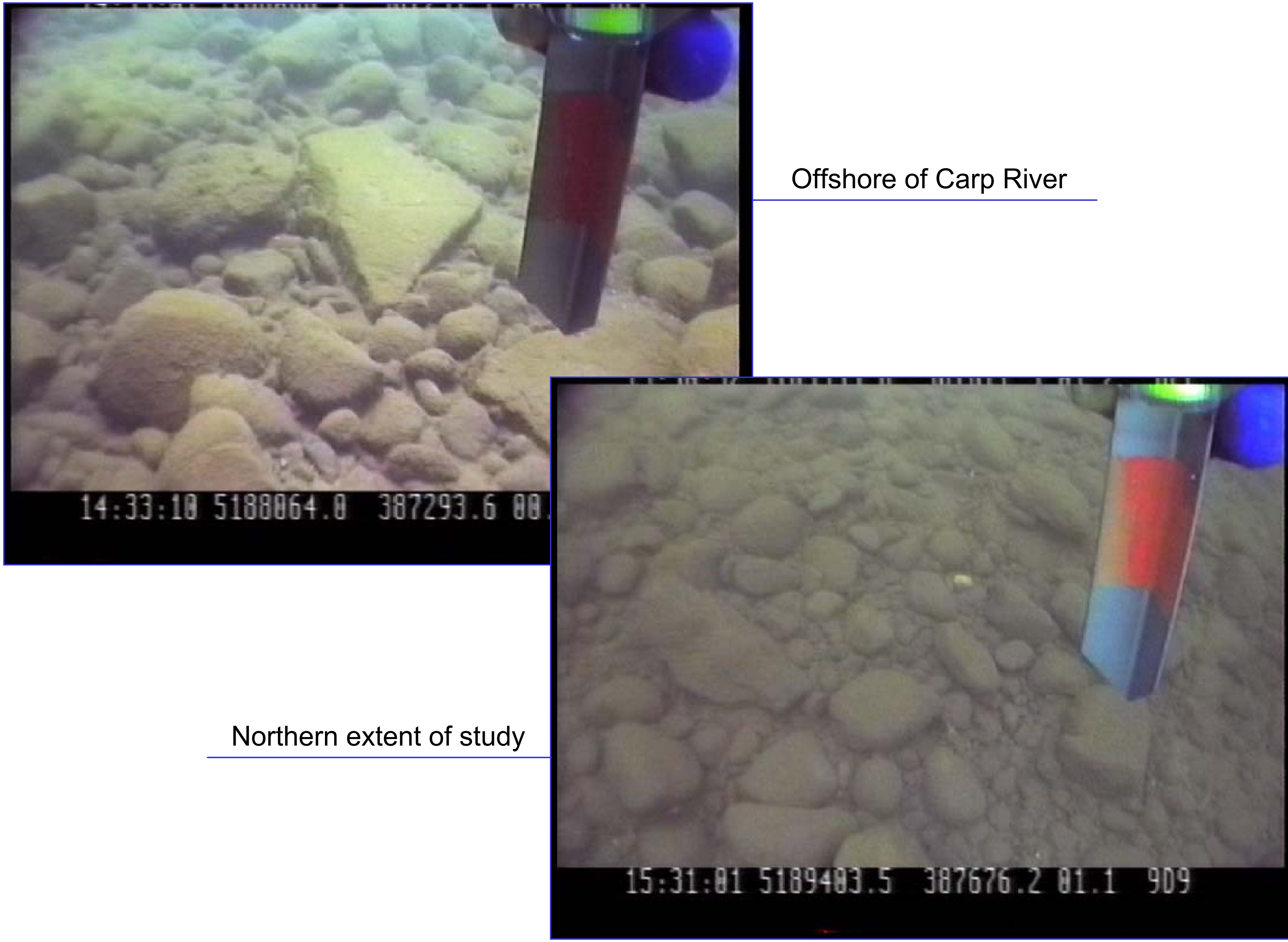


Figure 19: West Shore – cobble fields

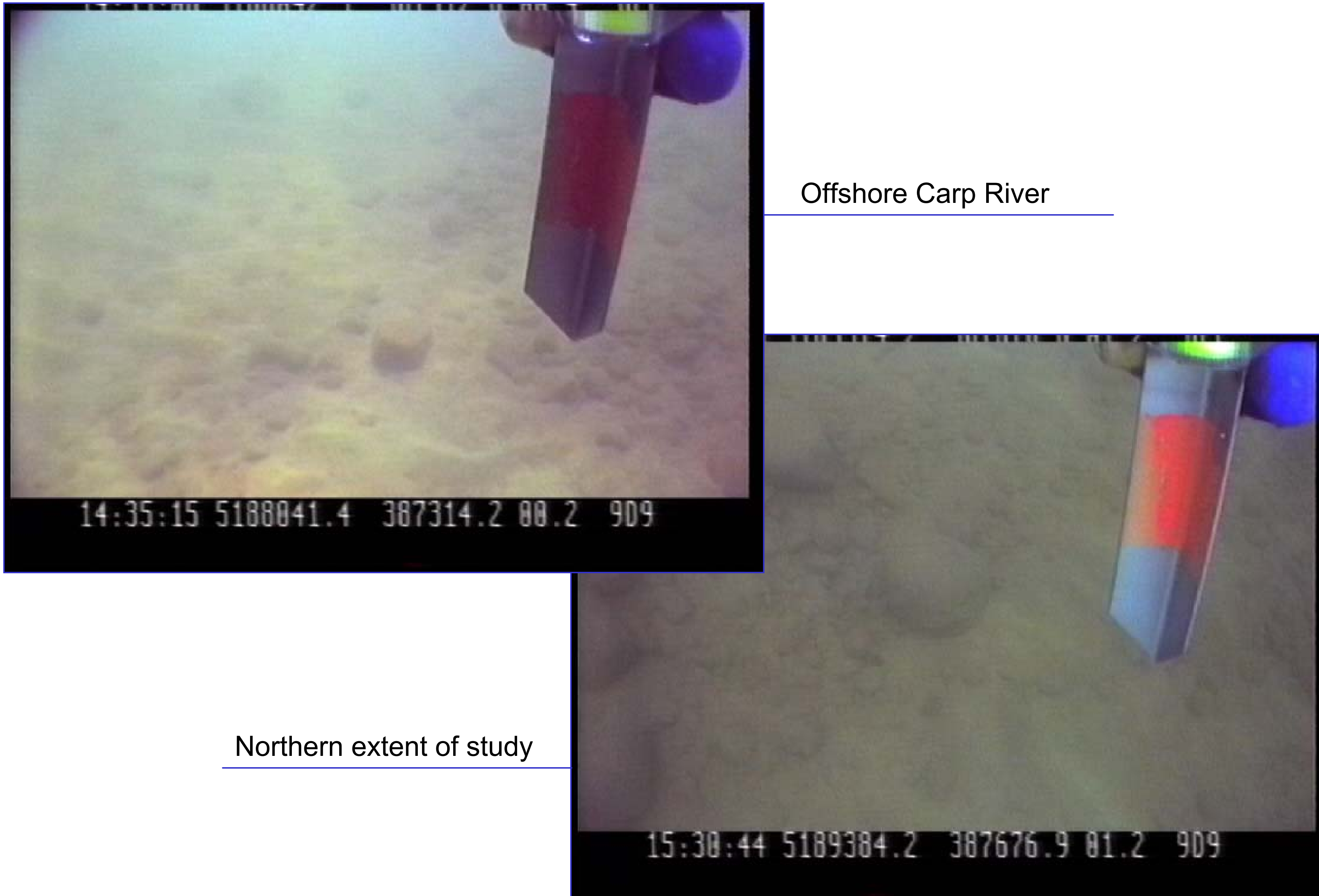


Figure 20: West shore – transition class substrate

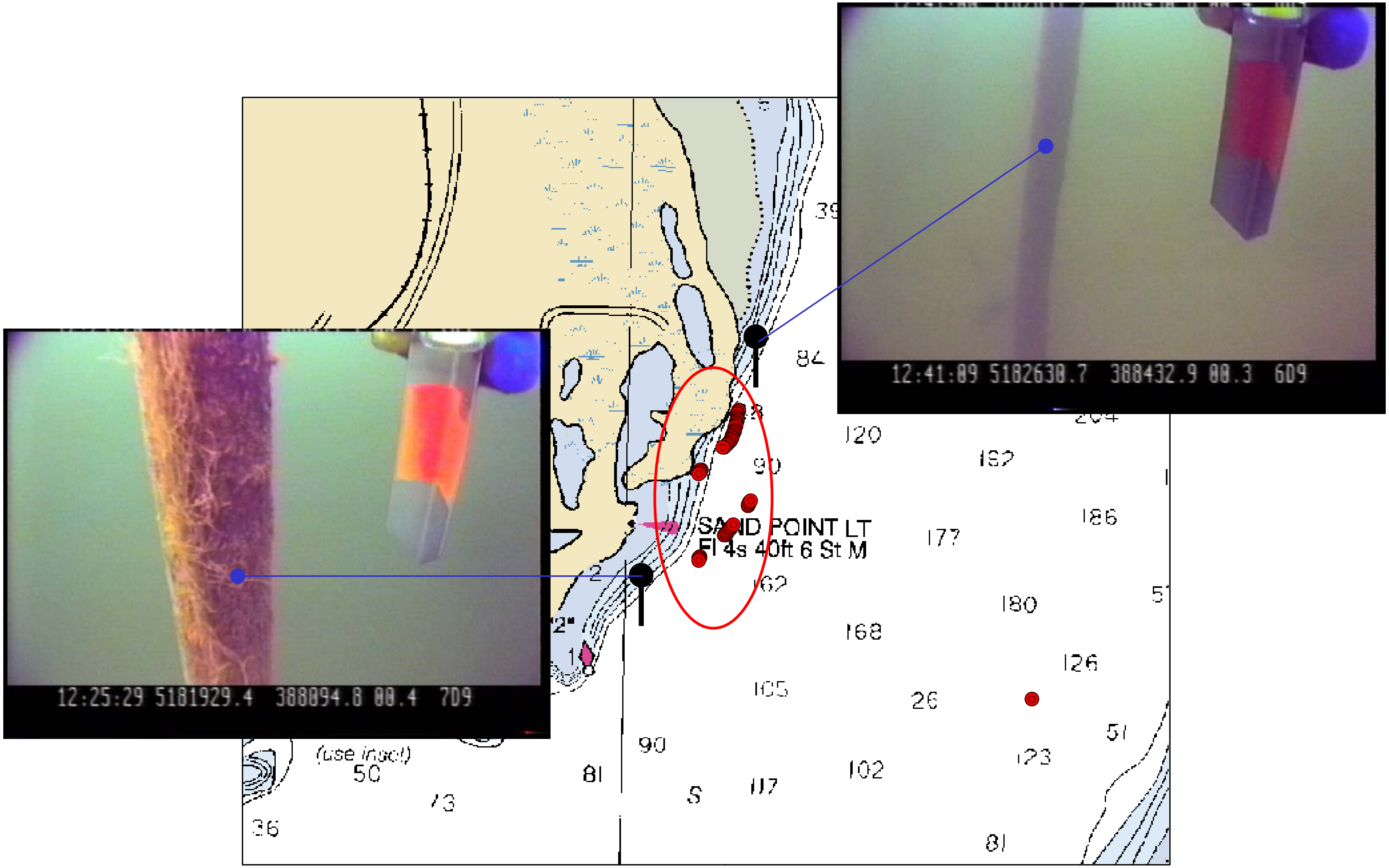


Figure 21: Area of extreme G1 measurements and location of submerged poles